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GENERAL DYNAMICS | CONVAIR

Report No. 8926-143

Material - Aluminum - 2020-T6, 2024-T3 and 7075-T6

Crack Propagation and Fatigue Characteristics

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Abstract:

Crack propagation tests were made with 20" wide by 40" long specimens of .079" thick 2020-T6, .0795" thick clad 2024-T3, .091" thick clad 2024-T3, .081" thick bare 7075-T6 and .091" thick clad 7075-T6 aluminum alloys. Initial 5 inch long cracks were introduced into each specimen and crack growth was observed as it related to incremental load increases. The fracture work rate for crack propagation was calculated according to the formula $dW/dA = \sigma^2 \pi x/2E$ where σ = max. gross stress, x = crack length at max. load and E = modulus of elasticity. The several crack propagation test results were as follows.

Material	dW/dA, in lb./sq.in.
.079" thick clad 2026-T6	144, 181
.0795" thick clad 2024-T3	1000, 990
.091" thick clad 2024-T3	1040
.081" thick bare 7075-T6	400
.091" thick clad 7075-T6	384

Axial fatigue curves were developed with the .079" thick 2020-T6 alloy in both the notched and un-notched conditions, and these are shown.

Reference: Lindeneau, G. D., Schiff, E., Wise, W. E., "Aluminum Alloy Sheet Evaluation, Crack Propagation and Fatigue Tests of Clad 2026-T6 Sheet," General Dynamics/Convair Report SL 58-283, San Diego, California, 23 February 1959. (Reference attached).

STRUCTURES & MATERIALS LABORATORIES

CONVAIR

A DIVISION OF GENERAL DYNAMICS CORPORATION

SAN DIEGO

REPORT SL58-283

DATE 23 February 1959

MODEL R & D 7038

REVISED 26 March 1959

TITLE

REPORT NO. SL58-283
ALUMINUM ALLOY SHEET EVALUATION
CRACK PROPAGATION AND FATIGUE TESTS OF
CLAD 2020-T6 SHEET
MODEL R & D
(7038)

PREPARED BY G. D. Lindeneau
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GROUP STRUCTURES LABORATORIES

REFERENCE

CHECKED BY W. E. Wise
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APPROVED BY E. F. Strong
E. F. Strong
Chief of Structures and
Materials Laboratorie.

WITNESS:
R. A. Miller - Mat'ls Group

NO. OF PAGES 15

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REVISIONS

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1	3/26/59	GDL	Changed Title, Figure No., and Table I	Title Page, 4 & 12
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ACCESS NO.

Title: MATERIAL - ALUMINUM - 2020-T6, 2024-T3 and 7075-T6. CRACK PROPAGATION AND FATIGUE CHARACTERISTICS.

Authors: Lindeneau, G. D., Schiff, E., Wise, W. E.
Report No.: 8926-143 Date: 23 February 1959
Contract No.: R.E.A. 7038
Contractor: General Dynamics/Convair
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(CONTINUED)

ACCESS NO.

Title: MATERIAL - ALUMINUM - 2020-T6, 2024-T3 and 7075-T6. CRACK PROPAGATION AND FATIGUE CHARACTERISTICS............. (Continued)

Axial fatigue curves were developed with the .079" thick 2020-T6 alloy in both the notched and un-notched conditions, and these are shown.

15 pages, 3 tables, 7 figures, 3 references.

INTRODUCTION:

The crack propagation characteristics of several materials have been reported. A proposal to use 2020-T6 aluminum alloy in the near future was being considered. This test was initiated in order to evaluate the crack propagation, mechanical, and fatigue properties of this material.

Parallel crack propagation and mechanical property tests were made on Clad 2024-T3 and Bare 7075-T6 materials.

OBJECT:

To determine:

a) The crack propagation characteristics of clad 2020-T6, clad 2024-T3, and bare 7075-T6 aluminum alloys.

b) The mechanical properties of the above three alloys.

c) The fatigue stress - cycle curves of notched and unnotched clad 2020-T6 aluminum alloy.

CONCLUSIONS:

a) The crack propagation tests show clad 2020-T6 to have the greatest tendency for crack propagation. This conclusion is based on the low $\frac{dw}{da}$ value (Reference Table I).

b) The longitudinal and transverse mechanical properties of the three materials tested may be found in Table II.

c) The clad 2020-T6 material has an unnotched million cycle life stress of 18,000 psi as compared to 26,000 psi for 2024-T3.

TEST SPECIMENS AND PROCEDURE:

Part a) Crack Propagation Tests

The test specimens were 20" x 40" long with the grain direction parallel to the 40" dimension. Five inches at each end were gripped in the fixture leaving a test section 20" wide by 30" long. The final cut in the test section was made by an .008" diameter jewelers saw. These cuts extended approximately .38" beyond the end of the preliminary cut. A drawing of the test specimen is shown in Figure 1.

The specimens were loaded in increments in a 400,000 pound universal standard Baldwin-Southwark testing machine. Crack measurements and photographs were made at each increment. The load increments were small in order that the failure load could be correlated with the slowly propagated crack length.

Part b) Mechanical Property Tests

Standard 2" gage length tensile specimens were cut both with and cross grain from each sheet of material used in this test.

The tensile yield, ultimate strength and 2" gage elongation were determined in a 12,000 pound Tinius-Olsen electromatic testing machine.

Part c) Fatigue Tests

Six notched and six unnotched specimens as shown in Figure 2 were cut from the two sheets of clad 2020-T6 material. Half of each type were cut from each sheet.

The axial fatigue tests were run at the stress levels shown in Table III and a stress ratio (R) = .05 in a Sonntag SF-1U universal fatigue machine (Reference Figure 3).

RESULTS:

Part a) Crack Propagation Tests

The resistance of a material to crack propagation (or tear resistance) has been investigated by a number of laboratories. The two methods in use to measure this resistance are:

1) The energy balance between strain energy and the work necessary to cause fracture.

2) The use of a stress concentration factor based on an effective notch radius.

The factors obtained by these methods vary from 3.35 to 1 from (1), to 5.50 to 1 from (2). The variance is a result of the specimen size and initial crack length. Emperical formulas developed for a more reliable estimate of the tear resistance show a variance in results based on specimen size as well as material type.

A thorough discussion of the theory involved is beyond the scope of this report; however, the results of the test are calculated on the basis of these theories and compared to the results of tests by other laboratories. The results are presented in Table I. The discussion of the tear resistance theory may be found in Reference 1.

The clad 2020-T6 material shows the greatest tendency for crack propagation by the low value of $\frac{dw}{da}$.

The comparison of data from previous investigators shows a reasonable correlation.

Photographs of the cracks from initial to just before failure are shown in Figures 4 through 6.

Part b) Mechanical Property Tests

The complete results from these tests may be found in Table II. A summation of the test is shown below by three specimen averages.

RESULTS: (Continued)

Part b) Mechanical Property Tests (Continued)

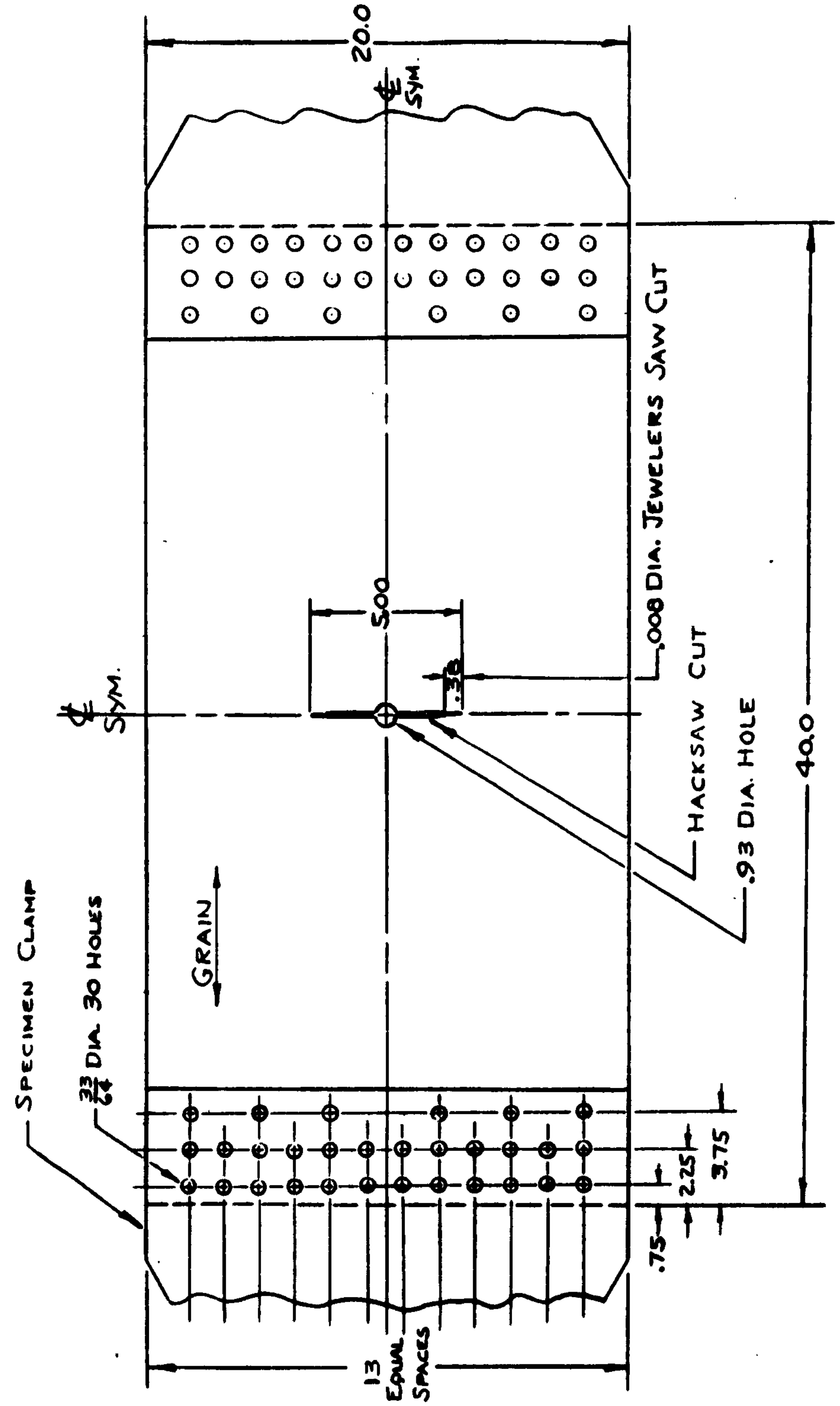
Material	Grain Direction	Yield Strength PSI	Ultimate Strength PSI	% Elongation 2" Gage
Clad 2020-T6	Long.	64,789	69,346	9.0
Sheet #1	Trans.	64,723	69,479	7.5
Clad 2020-T6	Long.	63,366	69,071	8.66
Sheet #2	Trans.	63,268	69,301	8.0
Clad 2024-T3	Long.	52,110	70,064	19.83
(One Sheet)	Trans.	45,966	67,414	19.83
Bare 7075-T6	Long.	76,173	83,097	14.5
(One Sheet)	Trans.	73,594	82,648	13.66

Part c) Fatigue Tests

The fatigue test results on clad 2020-T6 are listed in Table III and shown as an S-N diagram in Figure 7. Data from Reference 2 on clad 7075-T6 and from Reference 3 on clad 2024-T3 material has been added to the curve for comparison purposes.

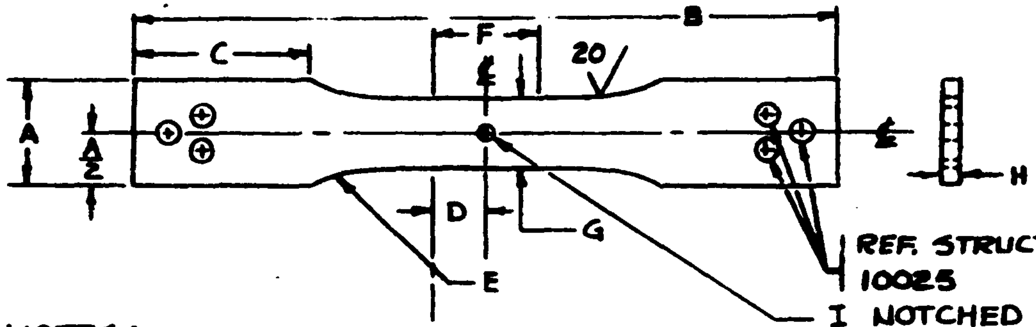
NOTE:

The test data from which this report was prepared are recorded in Structures Test Laboratory Data Book No. 4065, page 18.



CRACK PROPAGATION TEST SPECIMEN

FIGURE 1



NOTES:

1. I DIMENSION USED TO SPECIFY NOTCHED SPECIMENS – TYPICAL NO. 10026-1Na.
2. TYPICAL SPECIMEN NO. UNNOTCHED 10026-1.
3. THERE ARE TO BE NO NICKS, SCRATCHES, OR UNDERCUTS IN THE TEST SECTION.
4. UNLESS OTHERWISE SPECIFIED, TOLERANCES ARE AS FOLLOWS: .XX – ±.03 .XXX – ±.010; ANGULAR DIM. – 0°30'
5. HOLE PATTERN ℄ TO BE SYMMETRICAL TO TEST SECTION WITHIN .003 T.I.R.
6. MATERIAL TO BE AS SPECIFIED.
7. GRAIN DIRECTION TO BE LONGITUDINAL UNLESS OTHERWISE SPECIFIED.
8. FABRICATE IN ACCORDANCE WITH THE FOLLOWING PROCEDURE.
   - 8.1 SHEAR PANEL TO A & B DIMENSIONS.
   - 8.2 DRILL HOLE PATTERN TO DRAWING 10025
   - 8.3 BAND SAW TEST SECTION TO $\frac{1}{8}$ – $\frac{3}{16}$ OVERSIZE.
   - 8.4 ROUT TEST SECTION TO .005 OVERSIZE (5000 R.P.M. ROUTER).
   - 8.5 DRAW FILE & LONGITUDINALLY POLISH CUT EDGES. USE 0 THRU 000 EMERY PAPER. BREAK CORNERS OF TEST SECTION .005 MAX.

		-1	-3	-5	-7	-9	Kt NET	Kt GROSS
	A	3.00	2.00	2.00	1.50	1.00		
	B	13.72	10.98	9.80	9.36	4.37		
	C	3.00	2.00	2.00	2.00	.75		
	D	—	.50	—	—	—		
	E	10.00 R	7.00 R	6.00 R	6.00 R	3.00 R		
	F	—	1.0	—	—	—		
	G	1.000 ±.002	.660 ±.002	.500 ±.002	.250 ±.002	.250		
	H	.081 ±.005	±.005	±.005	±.005	±.005		
I	a	~~.250 ±.008~~		.125 ±.003			~~2.43~~	~~3.24~~
I	b	.187 ±.003		.093 ±.003			2.54	3.39

STRUCTURAL TEST
CONVAIR - SAN DIEGO
A DIVISION OF GENERAL DYNAMICS

TITLE: STANDARD FATIGUE SPECIMEN FLAT SHEET OR PLATE UNNOTCH & HOLE NOTCH.

MODEL	SCALE	DATE	DRAWN BY
	NONE	3-11-58	BRIGHT

S.O.

W.O.

DRAWING NUMBER 10026

B

6-899

CONVAIR SD - 3213

FIGURE 2

Figure 3 TYPICAL AXIAL FATIGUE TEST SETUPS FOR SHEET SPECIMENS

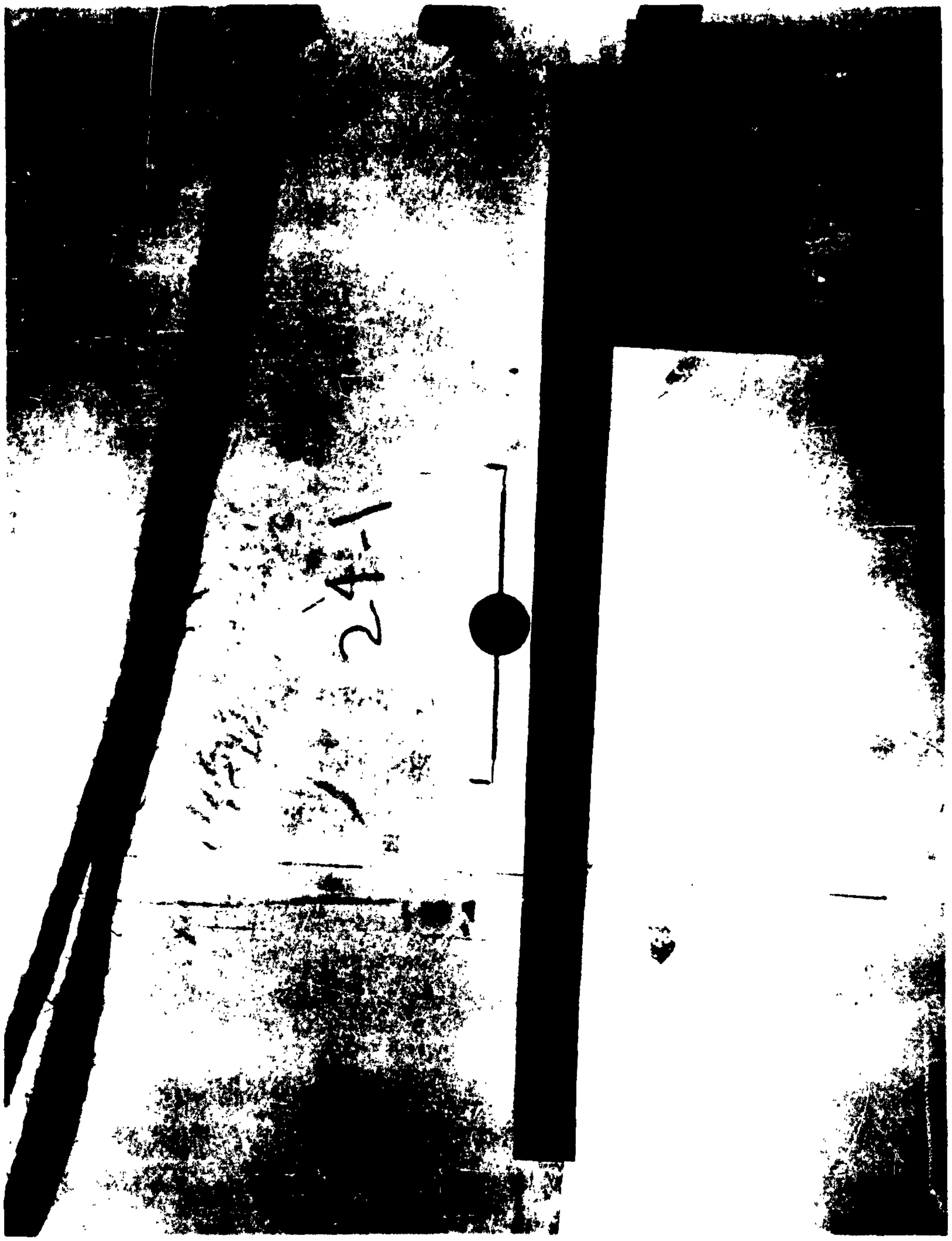


Figure 4 CRACK PROPAGATION PHOTO SHOWING TYPICAL INITIAL CRACK

Figure 5 CRACK PROPAGATION PHOTO SHOWING START OF STABLE CRACK GROWTH - CLAD 2024-T3 MATERIAL. NOTE DOUBLE CRACK AT EACH END.

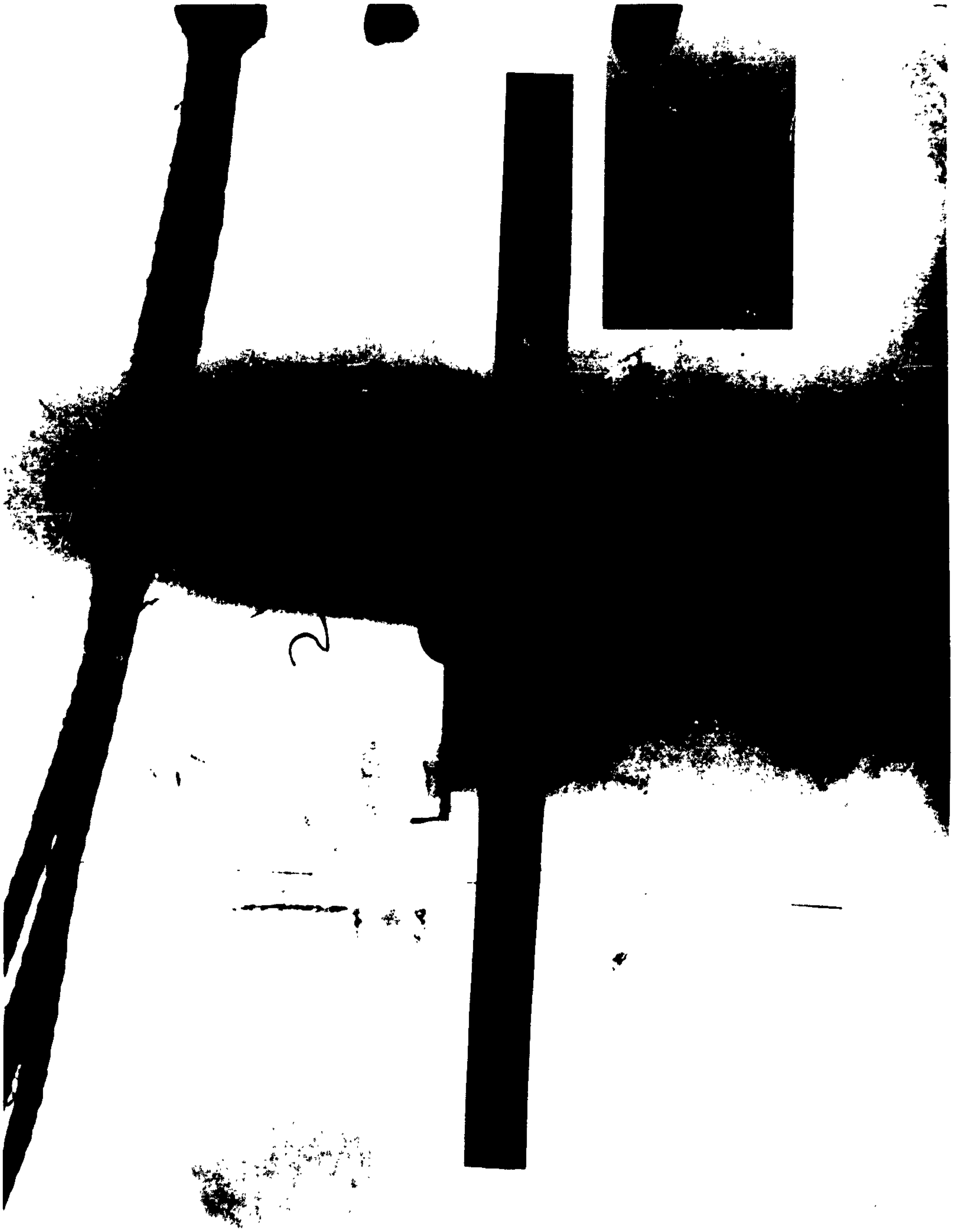


Figure 6 CRACK PROPAGATION PHOTO SHOWING STABLE CRACK GROWTH JUST PRIOR TO FAILURE - CLAD 2024-T3 MATERIAL.

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SAN DIEGO Division

MATERIAL: 2020T6 CLAD
Mfr —
Ht. No. —
Form: CLAD SHEET
F_{tu} = 69,000 PSI. F_{ty} = 64,000 PSI
El. = 9.0%
Surf. Fin. - L-17 Micro In, T-18 " "
Rockwell-"E" 95

SPECIMEN (Sketch and Dimensions)

⊙-CLAD 2020-T6-UNNOTCHED
⊡- " " "-NOTCHED
△- " 2024-T3-UNNOTCHED (REF. 3)
✪- " 7075-T6-UNNOTCHED (REF 2)

TEST CONDITIONS: Machine SONNTAG SF1U
R = .05 Mean Stress = —
Other —
Speed 1800 CPM Temp R.T
Date: 1-2 Kt (Net Section) = 2.5

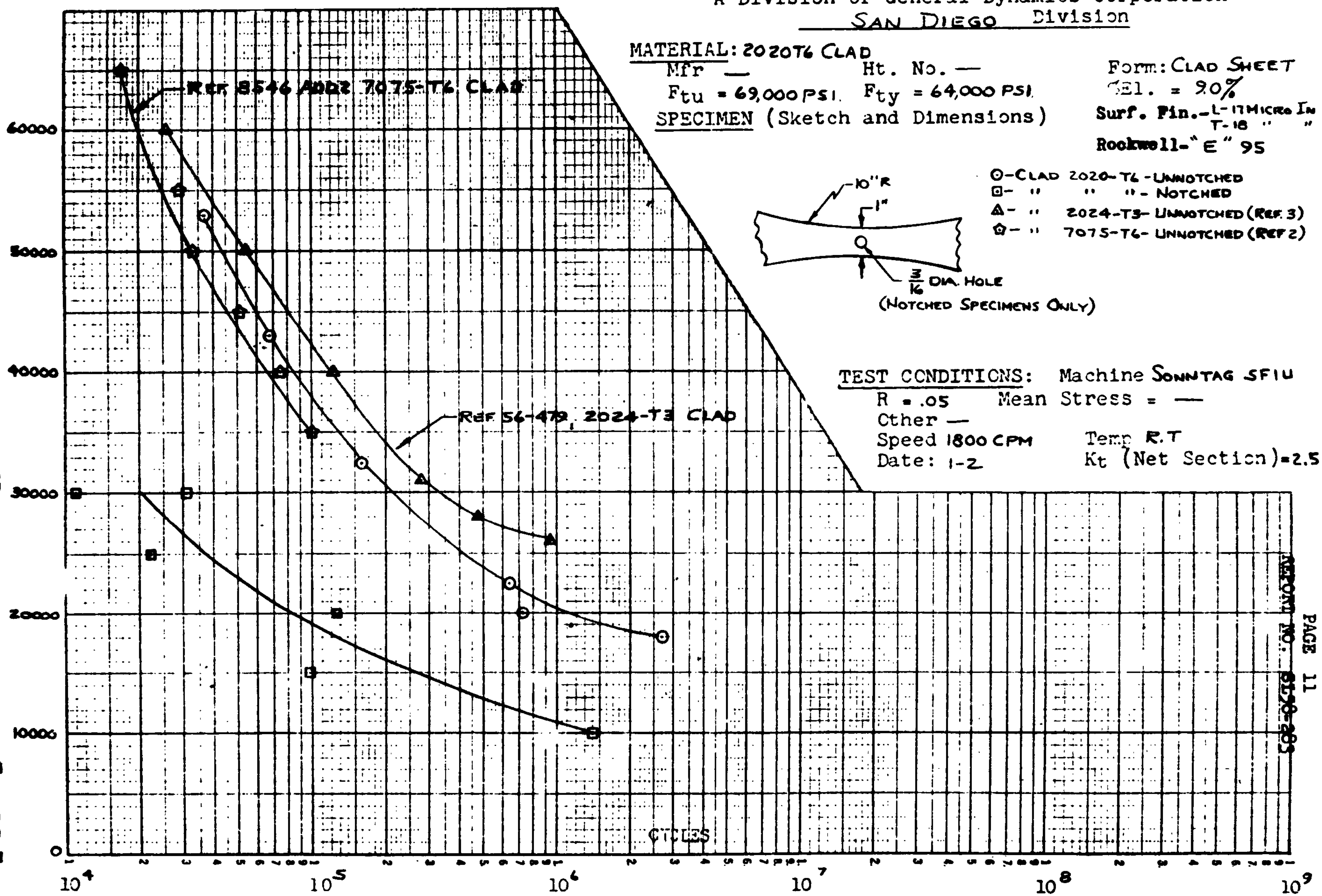

FIGURE 7

TABLE I - CRACK PROPAGATION TEST RESULTS

Material Type	Specimen Number	Sheet Number	Yield Str. Long PSI	Average Trans. PSI	Ultimate Str. Long PSI	Average Trans PSI	% Elong. 12" Gage Long	Average Trans	Specimen Width in.	Specimen Thickness in.	Initial Crack Length	Crack Length @ Max. Load	Max Load LBS.	Max Gross Stress PSI	Max. Net Stress PSI	dW/dA IN-LB./SQ. IN.
Clad 2020-T6	1	1	64,789	64,725	69,345	69,479	9.0	7.5	20.0	.079	5.00"	5.48"	22,400	14,150	19,500	144
	2	2	63,366	63,268	69,071	69,301	8.66	8.0	20.0	.079	4.99"	5.20"	24,900	14,450	21,200	181
Clad 2024-T3	1	1	52,110	45,966	70,064	67,414	19.83	19.83	20.0	.0795	5.00"	6.15"	48,400	30,400	43,600	1000
	2	1	—	—	—	—	—	—	20.0	.0795	4.99"	6.06"	48,150	30,250	43,800	990
* Clad 2024-T3	6	—	—	—	62,000	—	—	—	20.0	.091	5.40"	6.80"	48,400	26,500	40,200	1040
Bare 7075-T6	1	1	76,173	73,594	83,097	82,648	14.5	13.66	20.0	.081	4.99"	* *	33,600	20,750	—	—
	2	1	—	—	—	—	—	—	20.0	.081	4.97"	5.36"	35,000	21,160	29,500	400
* Clad 7075-T6	11	—	—	—	72,000	—	—	—	20.0	.091	5.34"	6.07"	34,600	19,000	27,300	384

* Data from Reference 1 for Comparison Purposes.

** First Specimen Tested - Final Crack Measurement Not Positive.

*** $E = 10.3 \times 10^6$, used for these calculations $\frac{dW}{dA} = \sigma^2 \frac{\pi X}{2E}$ = Fracture Work Rate for Crack Propagation, $\frac{\text{IN.LB}}{\text{SQ.IN.}}$

WHERE: σ = MAX. GROSS STRESS
X = CRACK LENGTH AT MAX. LOAD
E = MODULUS OF ELASTICITY

TABLE II - STATIC TENSILE TEST RESULTS

Material Type	Sheet Number	Thickness		Tensile Yield Strength			Tensile Ultimate Strength			2" Elongation - Percent	
				Longitudinal	Transverse		Longitudinal	Transverse		Longitudinal	Transverse
Clad 2020-T6	1	.079		64516	63896		69479	69479		9.0	7.5
		.079		65050	64268		69403	69231		9.0	8.0
		.079		64801	66005		69154	69727		9.0	7.0
			Average	64789	64723	Average	69345	69479	Average	9.0	7.5
	2	.079		64229	63806		68905	69403		8.0	8.5
		.079		61692	62250		69154	68500		9.0	8.5
		.079		64179	63750		69154	70000		9.0	7.0
			Average	63366	63268	Average	69071	69301	Average	8.66	8.0
Clad 2024-T3	1	.0795		52208	45570		69951	67204		19.0	20.5
		.0795		52221	47363		69969	67716		20.0	19.5
		.0795		51901	44966		70272	67322		20.5	19.5
			Average	52,110	45966	Average	70064	67414	Average	19.83	19.83
Bare 7075-T6	1	.081		76,702	73288		82564	82217		14.0	13.0
		.081		75881	73694		83333	82812		14.5	14.0
		.081		75938	73801		83395	82917		15.0	14.0
			Average	76173	73594	Average	83097	82648	Average	14.5	13.66

TABLE III

FATIGUE DATA - CLAD 2020-T6 ALUMINUM ALLOY

SPECIMEN NUMBER	MAXIMUM GROSS STRESS PSI	R	CYCLES TO FAILURE	NOTCHED	REMARKS
1-6	53,000	.05	37,000	NO	FAILED IN TEST SECTION
1-5	43,000		67,000		
1-4	32,500		159,000		
2-4	22,500		632,000		
2-5	20,000		721,000		
2-6	18,000	.05	2,680,000	NO	FAILED IN TEST SECTION
1-3	30,000	.05	31,000	YES	FAILED IN TEST SECTION
2-2	30,000		11,000		
1-2	25,000		22,000		
1-1	20,000		126,000		
2-1	15,000		98,000		
2-3	10,000	.05	1,415,000	YES	FAILED IN TEST SECTION

REFERENCES

1. J. Frisch, "Comparison of Semi-Emperical Solutions for Crack Propagation with Experiments" American Society of Mechanical Engineers Paper No. 57-SA-12, dated February 11, 1957.

2. G. D. Lindeneau, "XA 78S-T6 and 75S-T6 Clad Aluminum Alloy Sheet - Static and Fatigue Tests", Convair Engineering Test Laboratory Report No. 8545 Addendum 2, dated July 1955.

3. D. M. Forney, Jr., "The Effect of Artificial Aging on the Fatigue Behavior of Bare and Clad 2024 Aluminum Alloy", Convair Engineering Test Laboratory Report No. 56-479, dated October 20, 1956.